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Chromic Acid Anodizing of Aluminum Foil

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Space Administration

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CHROMIC ACID ANODIZING OF ALUMINUM FOILS

NASA CONTRACT NAS1-18224

TASK ASSIGNMENT NO. 7

FINAL REPORT

**PREPARED FOR
NATIONAL AERONAUTICAL AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
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FOREWORD

This report summarizes work accomplished by The Boeing Aerospace Company under NASA Contract NAS1-18224 Task No. 7, "Chromic Acid Anodizing of Aluminum Foil".

The program is sponsored by NASA Langley Research Center, Hampton, Virginia. Mr. Louis A. Teichman is the NASA Project Manager. Performance of this task was under the direction of the Parts, Materials and Processes Technology Organization, of The Boeing Aerospace Company, Seattle, Washington.

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1.0 INTRODUCTION

Graphite/epoxy (Gr/Ep) tubular struts comprise the baseline design for the Space Station truss structure. These struts are 2 inches in diameter, up to 23 feet long, lightweight, and possess the required stiffness. However, the low Earth orbit at which the Space Station will operate presents severe environment conditions for these composite structures. Primary environmental concerns are the effects of atomic oxygen and the temperature cycling resulting from passing through the Earth's shadow for 27 minutes during the 94 minute orbit. Previous studies at Boeing (funded by NASA LaRC) have shown that chromic acid anodized (CAA) aluminum foil is the most promising protective coating for these struts (Ref.1). The aluminum foil, bonded to Gr/Ep tubes, provides a barrier to atomic oxygen; anodizing provides the required optical properties to minimize thermal cycling temperatures and also improves adhesion of the foil to the composite.

This contract task was established to further develop and optimize CAA of aluminum foil for Space Station applications. CAA techniques for 24-ft-long x 8-in-wide x 0.003-in-thick foils were developed. This foil size is required to protectively wrap the longest struts of the truss structure. An anodizing specification was created describing the required CAA processing. Further development of bonding of anodized foil to Gr/Ep was also performed. A bonding specification was created describing the required adhesive bonding process.

The program was divided into three studies:

- Study 1 - Chromic Acid Anodizing of Aluminum Foil
- Study 2 - Bonding of Anodized Aluminum Foil to Graphite/Epoxy
- Study 3 - Chromic Acid Anodizing of Large Area Foils

2.0 CHROMIC ACID ANODIZING OF ALUMINUM FOIL

The targeted optical values of the CAA process were an air-mass 0 solar absorptance of 0.35 or less and a thermal emittance of 0.55 to 0.70. The low values of absorptance reduces maximum tube temperatures when tubes are exposed to direct or albedo radiation and the emittance values control the tube's

temperatures when exposed to deep space. A low specular reflectance, while maintaining the targeted absorptance and emittance, was also a design goal. This would provide the astronauts with a non-mirror-like surface to avoid glare while on EVA. A process specification detailing the Al foil alloy, temper, surface pretreatment, and CAA parameters that achieve the best anodized coating was developed. This specification titled "Chromic Acid Anodizing of Aluminum Foil Process Specification" is Appendix A.

2.1 Aluminum Foil Selection

This study was limited to evaluating various Al foils that could be procured "off the shelf", because extremely large orders are required to procure non-standard foils. Four Al foil alloys with various tempers were available for evaluation. The desired foil thickness was 0.003" which was the lightest weight Al foil that could be handled consistently without damage during the CAA processing of the 25-ft-long foils.

Alloy 1145 is very common and the most readily available of all the Al foil alloys. It is available as fully-soft (1145-0), half-hard (1145-H24) or fully-hardened temper (1145-H19) and in a variety of thicknesses. Alloy 6061 is fairly common but very rarely produced in thicknesses less than 0.005". Other alloys are occasionally available, as leftover sections of rolls. Al foil alloys and tempers available and evaluated were; 0.003" 1145-H19 and H24, 0.003" 5024-H19, 0.003" 3003-H19 and 0.005" 6061-0. These four alloys possessed similar solar absorptances of 0.08 to 0.17 and thermal emittances of 0.02 prior to anodizing. The variation in absorptance values were caused by sample orientation (because of the striations in the unanodized foil) and not due to alloying elements.

2.2 Aluminum Foil Evaluation

2.2.1 Anodizing Parameters

All CAA was performed within Boeing using various production facilities. Boeing has an industry accepted specification that controls anodizing of Al foils: BAC 5884, "Anodizing of Aluminum Alloys". This specification describes the requirements and process for racking, cleaning, CAA, and sealing of aluminum alloys. BAC 5884 provided the baseline approach to anodizing of Al

foil. Follow-up samples were anodized using modified parameters to arrive at the desired optical properties. No attempt was made to change the BAC 5884 cleaning process or sequence. The cleaning process consists of vapor degreasing (if required), alkaline cleaning, deoxidizing, and various hot and cold water rinses of the foil prior to anodizing.

The CAA parameters varied were immersion time in chromic acid solution, anodizing voltage (22 or 40 volts), ramp time to desired voltage and hot deionized water sealing. It was not possible to vary the chromic acid solution percentage of 7% (by weight), because the CAA was performed in production tanks. Previous work (Ref. 2) reported minimal changes in absorptance and emittance of CAA aluminum as a result of changing the chromic acid solution from 7.5% to 5%, when other parameters remained constant.

The two alloys that underwent extensive anodizing were 1145 and 6061. The 5024 and 3003 were in limited quantities and therefore, underwent limited characterization. The solar absorptance and emittance values as a function of CAA parameters, for all foils evaluated, are shown in Tables 1,2 & 3. Examination of the results show that:

1. Immersion time and anodizing voltage have the greatest impact on the optical values. The 1145 alloy anodized at 22 volts, 5 minute ramp and 50 minute immersion at full voltage achieved the targeted optical values. Increasing the voltage to 40 volts and decreasing the immersion time to 35 minutes also achieved similar optical values.
2. CAA of 6061 did not achieve the targeted optical values. The solar absorptance was too high (approximately 0.50) after foils were immersed long enough to achieve the minimum targeted emittance of 0.55. Limited testing showed 5024 and 3003 alloys to possess similar traits. Absorptance values for 6061 were approximately 40% higher than 1145 when anodized at the same parameters.
3. Hot deionized water sealing has minimal effects on absorptance, but increased the emittance on an average of 9-12% over unsealed samples, when other parameters remained constant. This effect was more noticeable at shorter immersion times.

1145-H19 Chromic Acid Anodized Aluminum Fail						
Anodizing parameters				Optical results		
Anodizing voltage	Ramp time to full voltage (mins)	Immersion time @ full voltage (mins)	Hot deionized water sealed (Yes/No)	Solar absorptance, α	Thermal emittance, ϵ	α/ϵ
22 ↑ 22 ↓ 40	5	25	No ↑	0.23	0.31	0.74
	5	30		0.24	0.37	0.65
	5	35		0.32	0.47	0.66
	5	40		0.35	0.51	0.69
	5	45		0.35	0.54	0.65
	5	50		0.34	0.57	0.60
	10	20		0.17	0.05	3.40
	10	30		0.31	0.44	0.70
	10	40		0.34	0.54	0.63
	15	25		0.15	0.03	5.00
	15	30		0.34	0.49	0.69
	15	35		0.35	0.48	0.73
	15	40		0.36	0.55	0.65
	5	10		0.24	0.16	1.50
		15		0.25	0.21	1.19
		20		0.29	0.33	0.88
		25		0.35	0.45	0.78
		30		0.38	0.51	0.75
		35		0.38	0.56	0.68
		40		0.39	0.55	0.71
		45		0.39	0.57	0.68
		50		0.39	0.57	0.68
		25	No ↓ Yes	0.38	0.56	0.68
		30		0.39	0.58	0.67
		35		0.38	0.58	0.66
		40		0.39	0.61	0.64
		45		0.39	0.62	0.63
40	5	50	Yes	0.39	0.62	0.63

Table 1 Chromic Acid Anodizing of 1145 Aluminum Foil

6061-0 Chromic Acid Anodized Aluminum Foil						
Anodizing parameters				Optical results		
Anodizing voltage	Ramp time to full voltage (mins)	Immersion time @ full voltage (mins)	Hot deionized water sealed (Yes/No)	Solar absorptance, α	Thermal emittance, ϵ	α/ϵ
40 ↑ ↓ 40	5 ↑ ↓ 5	10	No ↑	0.48	0.18	2.67
		15		0.47	0.28	1.68
		20		—	—	—
		25		0.48	0.50	0.96
		30		0.50	0.55	0.91
		35		0.52	0.61	0.85
		40		0.54	0.63	0.86
		45	No ↓ Yes ↑ No ↓ Yes ↑ No	0.50	0.60	0.83
		50		0.55	0.63	0.87
		10		0.47	0.18	2.67
		15		0.50	0.29	1.72
		20		0.49	0.39	1.26
		25		0.49	0.56	0.88
		30		0.51	0.65	0.78
		35		0.54	0.68	0.79
		40		0.54	0.68	0.79
		45		0.55	0.68	0.81
		50		0.57	0.69	0.83

Table 2. Chromic Acid Anodizing of 6061 Aluminum Foil

3003-H19 Chromic Acid Anodized Aluminum Foil						
Anodizing parameters				Optical results		
Anodizing voltage	Ramp time to full voltage (mins)	Immersion time @ full voltage (mins)	Hot deionized water sealed (Yes/No)	Solar absorptance, α	Thermal emittance, ϵ	α/ϵ
40 ↑ ↓ 40	5 ↑ ↓ 5	25 30 35 40	No ↑ ↓ No	0.44 — 0.43 0.47	0.43 — 0.46 0.58	1.02 — 0.93 0.81
5024-H19 Chromic Acid Anodized Aluminum Foil						
Anodizing parameters				Optical results		
40 ↑ ↓ 40	5 ↑ ↓ 5	25 30 35 40	No ↑ ↓ No	0.29 — 0.29 0.44	0.26 — 0.31 0.45	1.12 — 0.94 0.98

Table 3. Chromic Acid Anodizing of 5024 and 3003 Aluminum Foil

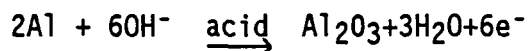
2.2.2 Smut Evaluation

CAA foils immersed for the 35-50 minutes (required to achieve the desired emittance) exhibited an olive green tint that darkened with immersion time. Difficulties were encountered in achieving the minimal targeted emittance of 0.55 while not exceeding the targeted solar absorptance of 0.35, caused by the darkening of the foil. Tests were performed to determine if this was caused by smut forming on the foil during the anodizing process and therefore, preventable or if this was inherent to the CAA process. Smut is defined as the deposition of alloying constituents onto the surface of the foil during processing. The cleaning and etching processing prior to anodizing were suspect in causing smut to be deposited on the aluminum foil.

BAC 5884 was followed to process 1145 and 6061 aluminum foil specimens. Two tests were performed between each processing step and after one minute of anodizing at full voltages: 1) The foil was wiped with a clean cheese cloth which was checked for dark discoloration, indicating smut, and 2) nitric acid was washed over the foil specimen, collected and neutralized. A blue tint would indicate the presence of copper smut.

Three different anodizing process lines were used, each of which used a different deoxidizer. These deoxidizers were Amchem 6-16, Amchem 6-17 and a Boeing proprietary product called Boclene. All three are classified as being heavy duty deoxidizers and smut removers. All tests proved negative for smut. This indicated that the olive green tint was inherent to the CAA process. A discussion of why this happens follows:

Anodizing forms a layer of α -aluminum oxide on the surface electrochemically by making it the anode in an acid solution and passing an electric current as follows:



The process of anodizing is visually recognized by a perception of color on the dry surface. Phosphoric acid anodizing imparts a yellow-green to purple color; sulfuric acid anodizing imparts no color but appears cloudy because of

hydrate diffraction; and CAA imparts a light green to brown color, depending on immersion time.

The aluminum oxide structure is hexagonal and, therefore, is able to be either 1) substituted in the lattice, or 2) bonded by sharing d-orbitals. For example, Cr^{+6} in chromate ion has an ionic radius of 0.52 \AA compared to 0.51 \AA of Al^{+3} in alumina, so substitution is possible. Upon excitation, the anodize appears green due to the chromium emittance of light. The shade can be "muddied" by hydrate levels and contamination alloying constituents. Sulfuric acid anodize and phosphoric acid anodize emit differently due to their inherent structures.

2.3 Nonspecularity of Aluminum Foil

Aside from varying anodizing parameters, three methods have been identified which effect the specularity of Al foil. They are: 1) mechanical abrading or 2) chemical etching of the foil prior to anodizing, and 3) texturing of the foil during the bonding of the foil to Gr/Ep. This texturing technique was used on the foil wrapped tubes previously fabricated and delivered to NASA LaRC by Boeing (Ref. 1). Mechanically abraded Al foil, called scratch-brushed, is used to provide a matte finish for items such as name plates or to improve adhesion when bonding. During the scratch-brushing operation, one side of the foil is mechanically abraded to provide the textured surface. Scratch-brushed 1145-H19 foil that is 0.003" thick is currently available in roll lengths and adds 15-20% to the total cost.

The industry standard for applying a matte finish to the foil is to scratch-brush foil which is thinner than 0.012" and chemically etch (using sodium hydroxide as the caustic ingredient) the thicker foil. Chemical pretreatment of the 0.003" and the 0.005" foil was evaluated. Difficulty was encountered in finding etchants that have an impact on the surface texture but are not hazardous to the personnel using them. Several 0.003" 1145 foil samples were processed in sodium hydroxide. Samples were then lightly anodized (40 volts, 5 minute ramp and 15 minute immersion time) and differences in optical values determined. There was little change in specularity, emittance, and absorptance between samples immersed up to 15 minutes in the sodium hydroxide and control specimens.

2.4 Atomic Oxygen Testing

One inch diameter discs of unsealed CAA Al foil were tested to determine if short term exposure to atomic oxygen caused changes in optical properties or mass loss. The discs were exposed for 48 hours in the atomic oxygen materials screening facility at Boeing. This facility is a vacuum chamber made primarily of glass and is essentially a 6" diameter cylinder with a 3" diameter side arm attached. The oxygen atoms are produced within a plasma created by an RF discharge in the sidearm. The plasma is confined to the side arm region by use of a balanced RF circuit. The samples are mounted in an aluminum holder, held at 185°F during exposure, and placed perpendicular to the flux in the 6" diameter cylinder. Because the plasma is confined to the side arm, the samples are not exposed to any ions or UV radiation.

The flux is approximately 40 to 400 times orbital rates depending on sample location. A key difference between the AO facility and orbital conditions are the thermal energies of the oxygen atoms. In the lab facility they are approximately 0.1 to 0.2 ev, but in orbital collisions they are approximately 5 ev. The 48 hours exposure in the lab delivered a fluence of approximately 7×10^{21} oxygen atoms/cm² to the sample surface.

There was no change in either solar absorptance and emittance of the four samples and no mass loss. During the 48 hours of exposure 0.002" thick Kapton exhibited approximately 12-15% mass loss.

2.5 Results and Conclusion

The 0.003" 1145-H19 and/or 1145-H24 Al foil CAA for 50 minutes at 22 volts or 35 minutes at 40 volts, both with a ramp time of 5 minutes, was selected as the optimum foil and anodizing parameters for the following reasons:

1. Alloy 1145 was the only alloy evaluated that achieved the targeted optical properties. The composition of the 6061, 3003 and 5024 prevented these Al foil alloys from achieving the desired absorptance and emittance.
2. Alloy 1145 foil at 0.003" was the only alloy readily available "off the shelf". It was primarily available in the H19 temper

(fully-hardened), but also can be purchased in the H24 temper (half-hard). The fully-hardened temper minimized the chances of wrinkling and creasing of the foil during processing. The H24 temper is the easiest to work with when wrapping Gr/Ep tubes. Temper selection should be based on experience of shop personnel.

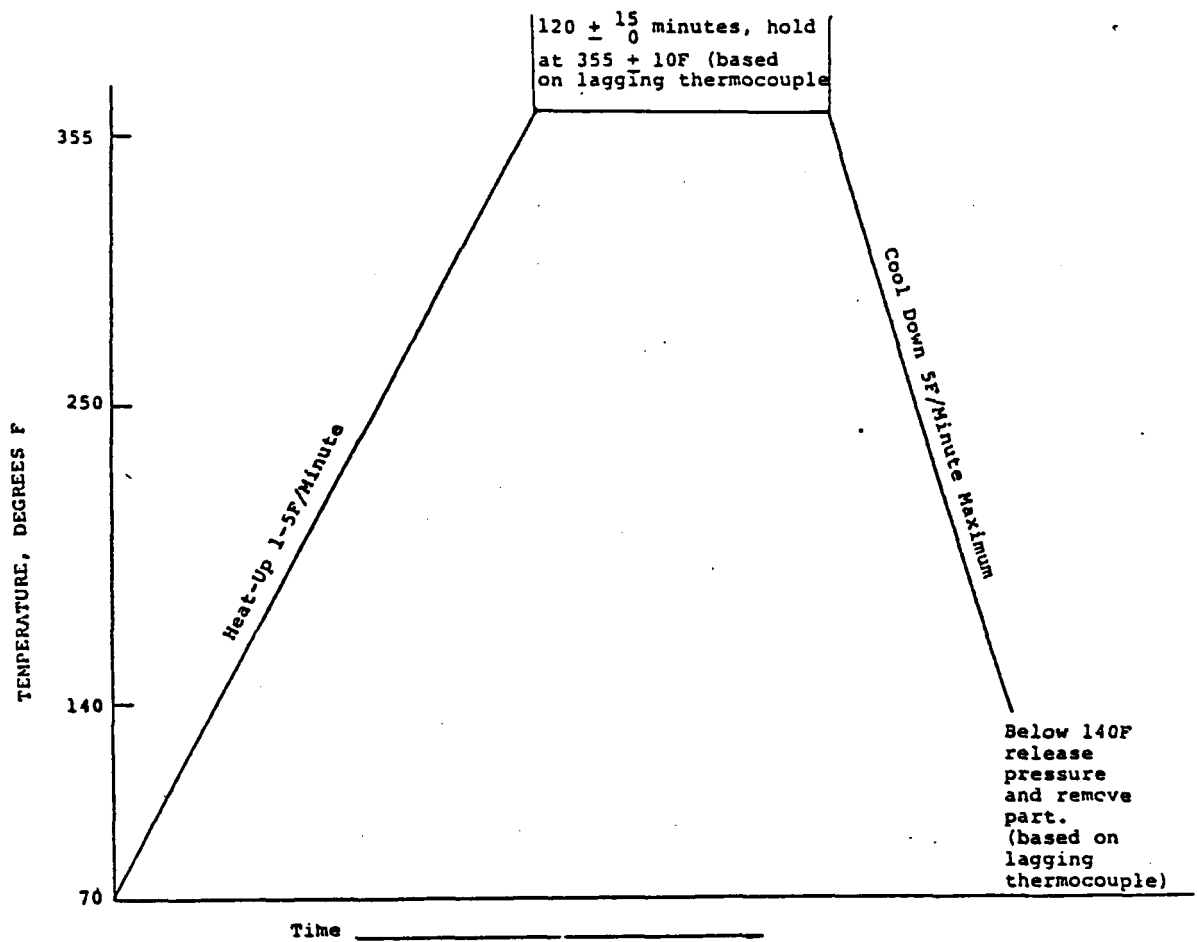
3. While varying anodize parameters of the CAA process permits optical tailoring of the anodized foil, targeted optical properties of the contract required the foil to reach the saturation limit of the CAA process. As shown in Table 1, once the foil reached an emittance of 0.55 and a solar absorptance of 0.35 no further major changes in optical properties occurred.
4. Hot deionized water sealing is expected to prevent any staining during handling and is easily performed. A side benefit of sealing was increased emittance while absorptance remained constant, when compared to unsealed foils.
5. The nonspecularity provided by foils that met the required emittance and absorptance goals was sufficient to eliminate the need for surface pretreatment prior to anodizing.

3.0 BONDING OF ANODIZED ALUMINUM FOIL TO GR/EP

Bonding specifications were developed that provide the best adhesion of the CAA Al foil to Gr/Ep while minimizing the thickness of the epoxy film adhesive layer between the foil and Gr/Ep. This specification titled "Adhesive Bonding of Anodized Aluminum Foil to Graphite/Epoxy Tubes" is Appendix B. Room temperature peel testing was conducted to determine the effect of primer, sealing, adhesive thickness, and co-curing or secondarily bonding of the anodized foil to Gr/Ep. Primer is sprayed onto the backside of the anodized foil to promote adhesion between the foil and epoxy film adhesive. The Gr/Ep used for peel testing substrates was T300/934 which was cured using the cure cycle shown in Figure 1. Secondarily bonded foil is applied similar to co-cured foil and then cured in a 250F oven for one hour with the foil/adhesive/tube under vacuum. This approach is taken if the tube has been previously cured without foil on the exterior surface. Secondary bonding also requires tube surface preparation before applying the foil/adhesive. Previous work (Ref. 3) evaluated Gr/Ep surface preparation for secondary bonding using a number of mechanical pretreatment methods including; peel ply, abrasive grit blasting, sandpaper and surface conditioning using an abrasive pad called SCOTCHBRITE. Test results showed SCOTCHBRITE to equal or better the other methods evaluated. Based on these results, SCOTCHBRITE was the only surface pretreatment evaluated.

The epoxy film adhesives evaluated were American Cyanamid 0.003" and 0.005" FM 300 (350F cure) and 0.005" FM 73 (250F cure). Test were also performed to determine if an adhesive is required to achieve an adequate foil to Gr/Ep bond during co-curing.

The instrumentation used for the peeling testing included a 10 lb load cell and a 60" displacement transducer. The test specimen was installed in a hold down fixture and the free end of foil was then clamped to a load rod that was attached to the crosshead of the test machine. The load rod pivoted, keeping the angle of pull close to 90° throughout the peel test. The load cell and displacement transducer provides a plot of load vs displacement. These were analyzed to determine the individual peel strengths. All specimens were 1" x 6" strips of foil bonded to 2" x 8" sections of Gr/Ep. The first 1" of



- Apply 22 inches Hg vacuum minimum to vacuum bag
- Apply 85 \pm 15 psig pressure for prepreg precuring operations
- 0
- Apply 45 \pm 5 psig pressure for secondary bonding operations
- 15
- Apply 45 \pm 5 psig pressure for cocuring operations
- Maintain pressure under diaphragm of 0 psig

Vent vacuum bag to
atmosphere when pressure
reaches 20 psig

Figure 1 T300/934 Graphite/Epoxy Cure Cycle

foil was not bonded to enable clamping to the load rod. The following test results were obtained by peel testing over 70 specimens. No thermal cycling was performed. The results are in decreasing order of peel strength.

1. Co-cured 0.005" FM 300 with primer
Both sealed and unsealed specimens possessed peel strengths that tore ten out of twelve foils during testing. Average peel strength was 9 to 15 lbs/in
2. Co-cured 0.003" FM 300 with primer and sealed
Average peel strength was 7.5 to 9 lbs/in
3. Secondarily bonded 0.005" FM 73 with primer and unsealed
Average peel strength was 7.5 lb/in
4. Secondarily bonded 0.005" FM 73 with primer and sealed
Average peel strength was 3.75 lbs/in
5. Co-cured 0.003" FM 300 with primer and unsealed
Average peel strength was 3.5 lbs/in
6. Co-Cured sealed foil using no adhesive or primer
Average peel strength was 3.5 lbs/in
7. Co-cured unsealed foil using no adhesive or primer
Average peel strength was 2.5 lbs/in with wide variation in data

The remaining testing showed that bonding without primer and using the 250°F primer for 350°F curing resulted in unacceptable peel strength of 1.5 lbs/in or less.

Test results showed that excellent foil to Gr/Ep peel strength can be achieved using either co-cured or secondary bonded Al foil. The testing also showed that hot deionized water sealing of the CAA foil increased peel strength of co-cured foils but lowered peel strength of secondary bonded foils. Minimum acceptable peel strengths have yet to be determined for the Space Station truss structures application.

4.0 CHROMIC ACID ANODIZING OF LARGE AREA FOILS

CAA of aluminum foil that is long enough to continuously cover the diagonal tubes in the Space Station truss structure requires anodizing of 24-ft-long x 8-in-wide x 0.003-in-thick foils. The anodizing process was performed in Boeing's Anodize and Alodining Shop located in Plant II. This is a very high volume production shop that operates seven days/week, three shifts/day. The alkaline cleaner, deoxidizer, anodizing and rinse tanks (shown in Figure 2) are a minimum of 60-ft-long x 4-ft-wide x 10-ft-deep. Each tank has a working capacity of over 20,000 gallons. The deionized, hot water tank is 16-ft-long x 4-ft-wide x 10-ft-deep with a 3000 gallon capacity.

4.1 Racking

The largest foils anodized were 25-ft-long x 44-in-wide x 0.003-in-thick. Each of these foils provides four of the required 8-inch-wide strips. Figure 2 & 3 shows three of these foils being processed at the same time. When anodizing foil sections as large and as thin as these foils, racking is required to provide structural support along with the required electrical contact. Without adequate support, the foil would become wrinkled and creased during processing. The racking design that proved to be the most successful is shown in Figure 4.

Racking the foil consisted of cutting the 44-in-wide foil to length and then laying flat next to a 25-ft-long, 2" x 2" x 1/8" aluminum angle section. The foil is clamped to the angle section using plastic C-clamps. The angle section/foil is then transferred to the anodizing hood and clamped to bars hanging down from the anodizing hood. These bars are positioned so the angle section is supported at the ends and in the middle. Note that once the angle section is clamped in place, all clamps are positioned so any drainage during rinsing and drying is directed away from the anodized surface, minimizing streaking of the backside of the anodized foil. A second similar angle section is clamped along the bottom of the bars and the foil is clamped to it. Once this step has been completed, the foil is ready for the anodizing process.

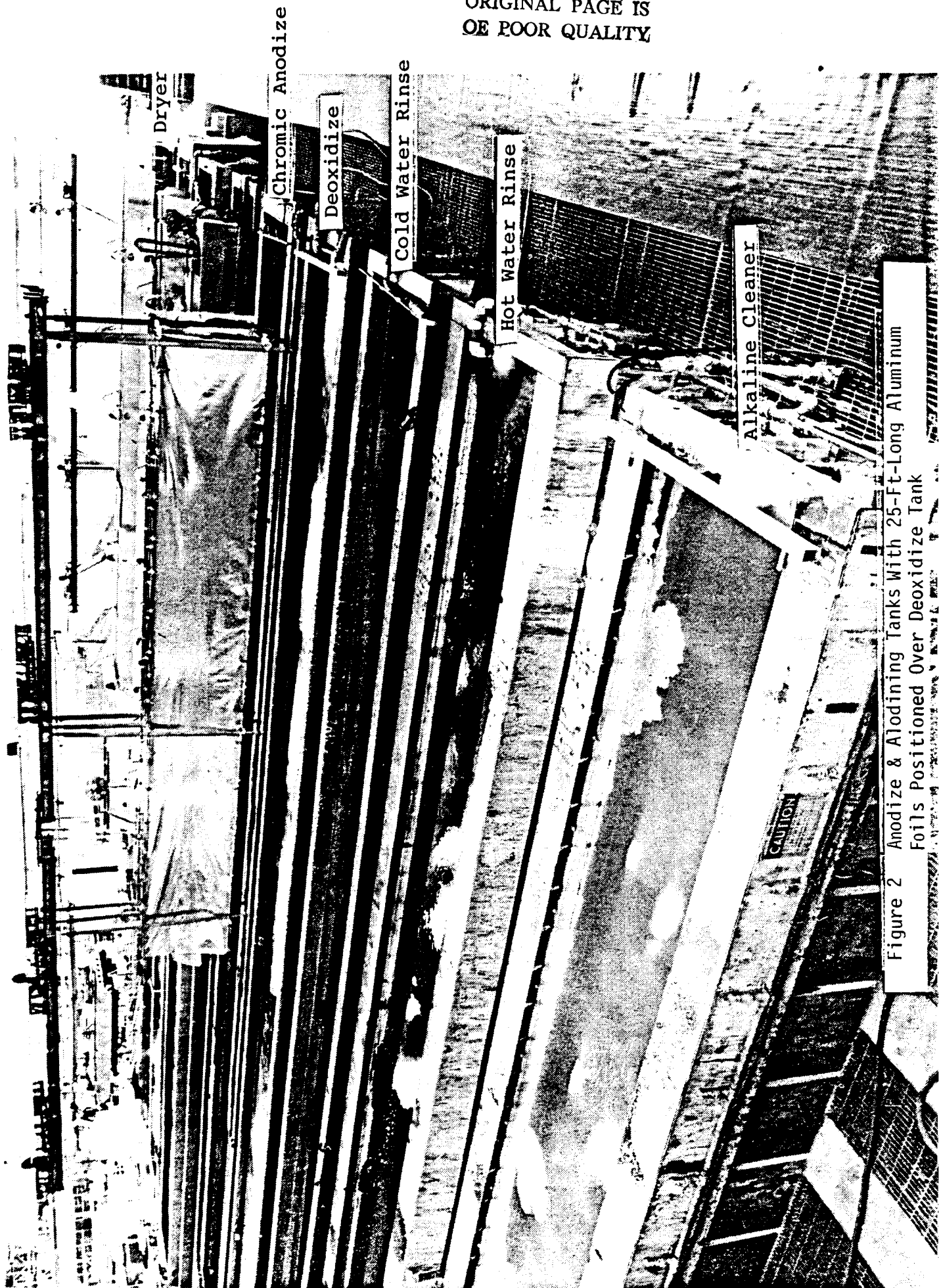


Figure 2 Anodize & Alodizing Tanks With 25-Ft-Long Aluminum
Foil Positioned Over Deoxidize Tank

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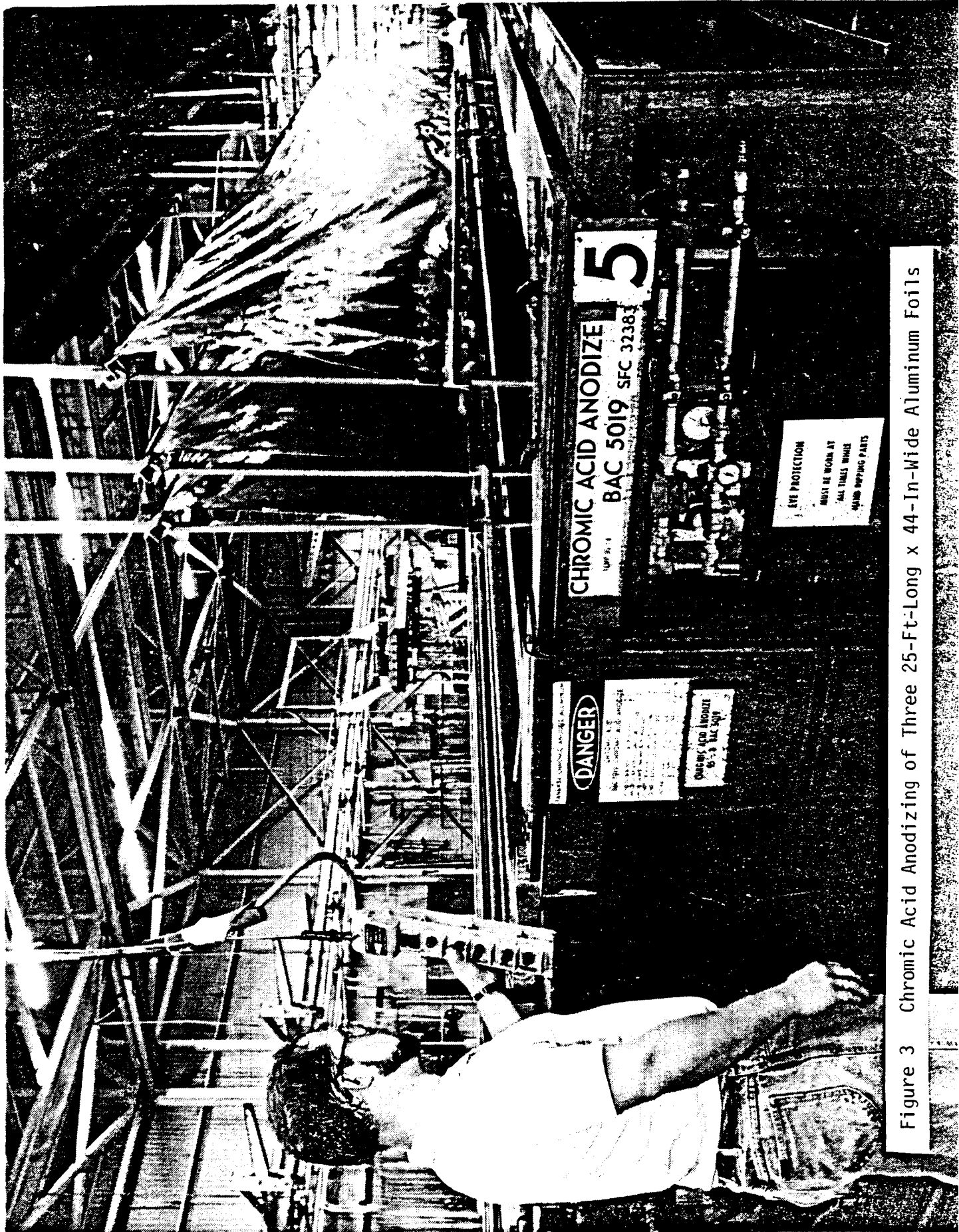


Figure 3 Chromic Acid Anodizing of Three 25-Ft-Long x 44-In-Wide Aluminum Foils

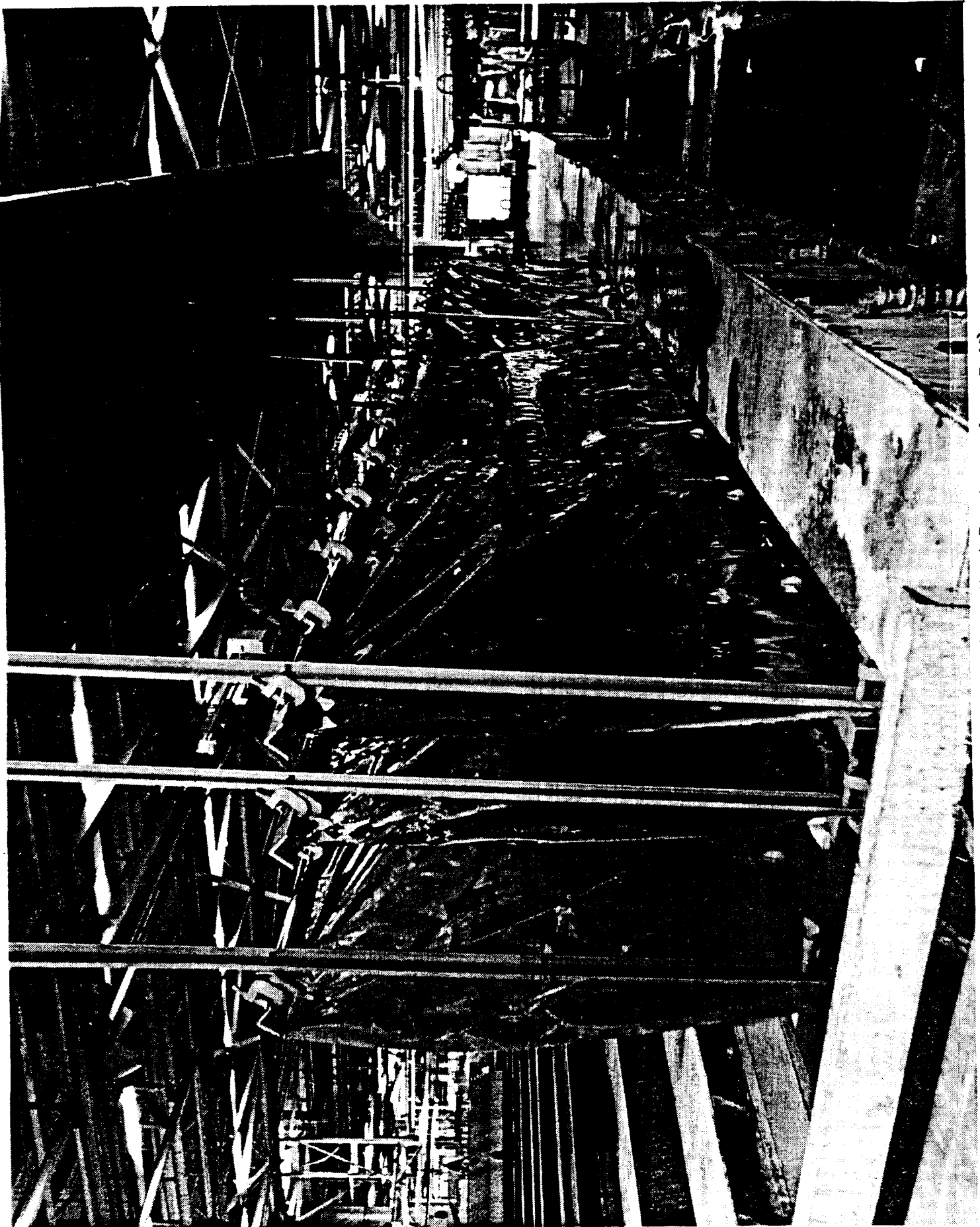


Figure 4 Racking Scheme Used For Large Area Foils

This rack design proved to be the simplest that provided adequate structural support and electrical contact. The plastic C-clamps used were fabricated by Duraclamp and are made from a phenylene oxide-based resin. This clamp material is resistant to chemical attack by the solutions used in the anodizing process. However, the clamps should not be used in a vapor degreasing operation because Freon is capable of dissolving the clamp material.

The foils that required sealing were unracked following the anodize cold water rinse and transferred to a smaller hood, because the hot deionized water seal tank was not long enough to handle the 25-ft-long racking. The foil was then clamped around the perimeter of the hood and lowered in the seal bath. This concept worked well because no electrical contact was required between the foil and hood.

4.2 Results and Conclusion

Once a successful rack design was completed, the anodizing of the large area foils went smoothly. Al foil alloys and tempers that were anodized in 25-ft-lengths were 1145-H19, 1145-H24 and 6061-0. The optimum processing was performed, as outlined in Chromic Acid Anodizing of Aluminum Foil Process Specification except that voltage was limited to 22 volts. It was determined that vapor degreasing was not required for foils received in coil form from the various vendors.

Uniformity of optical properties throughout the 25-ft-lengths was excellent and the targeted optical values achieved. The foils delivered to NASA LaRC possessed a solar absorptance of 0.31 and a thermal emittance of 0.60 to 0.64 for the four unsealed foils and a solar absorptance of 0.33 and an emittance of 0.67 for the sealed foils. No wrinkling or creasing of the foils occurred when handled properly. It was determined that the aluminum racking should be stripped after each use which enables satisfactory electrical contact between the foil and racking.

5.0 RESULTS AND CONCLUSIONS:

The 1145 Al alloy was the only alloy evaluated that achieved the desired optical goals of a solar absorptance of 0.35 or less and a thermal emittance of 0.55 to 0.70. The alloy composition of 6061, 3003 and 5024 prevented these Al foil alloys from achieving the desired optical properties using the CAA process. 1145 foil also was the only foil readily available "off the shelf" in a variety of thicknesses and tempers. The fully-hardened temper minimizes chances of wrinkling and creasing of the foil during processing while the half-hard temper is the easiest to work with when wrapping Gr/Ep tubes.

Hot deionized water sealing is expected to increase resistance to soiling and staining during handling. The sealing process is easily performed and possesses a side benefit of increasing emittance while the absorptance remained constant.

Peel testing results showed that excellent Al foil to Gr/Ep peel strengths are achieved using either co-cured or secondary bonded Al foil with primer and epoxy film adhesive. Testing also showed that hot deionized water sealing increased peel strengths of co-cured foils but lowered peel strengths of secondary bonded foils. Co-cured foils using no primer and epoxy film adhesive possessed marginal peel strengths. A specification titled "Adhesive Bonding of Anodized Aluminum Foil to Graphite/Epoxy Tubes" was developed and included as an appendix in this report.

CAA of 25-ft-long by 44-in-wide foils was accomplished with up to three foils being processed at the same time. Uniformity of optical properties throughout the 25-ft-lengths was excellent. A process specification titled "Chromic Acid Anodizing of Aluminum Foil Process Specification" was developed and included as an appendix in this report.

In conclusion, CAA 0.003"-thick 1145 Al foil adhesively bonded to the Gr/Ep Space Station tubular struts provides a superior protective and thermal control coating in the LEO environment. The anodized foil protects the Gr/Ep from degradation caused by atomic oxygen, minimizes the temperature gradients in the composite struts and provides passive thermal control. Techniques to CAA of foils long enough to continuously cover the diagonal struts in the

Space Station truss structure were successfully developed.

6.0 REFERENCES

1. Kelleher, T. M., "Thermal Control Properties of Immersion and Repair Anodic Coatings", Symposium on Anodizing Aluminum, April 12, 1967, pg. 71.
2. Dursch, H. W. and Hendricks, C. L. "Development of Composite Tube Protective Coatings", NASA CR-178116, July, 1986.
3. Pocius, A.V. and Wenz, R. P., "Mechanical Surface Preparation of Graphite/Epoxy Composite for Adhesive Bending", SAMPE Journal, September/October, 1985, pg. 50.

APPENDIX A

CHROMIC ACID ANODIZING OF ALUMINUM FOIL PROCESS SPECIFICATION

1.0 SCOPE

This specification establishes the requirements and processes for chromic acid anodizing (CAA) of aluminum foil, including the required cleaning and deoxidizing processes performed prior to anodizing. The targeted optical values of the anodized foil are a solar absorptance of less than 0.35, integrated over an air-mass 0 (space environment) solar spectrum, and a thermal emittance of 0.55 - 0.70. Also included are requirements and processes for deionized water sealing of CAA foil.

2.0 DEFINITIONS

Water-Break-Free: A surface condition which maintains a continuous water film for a period of at least 30 seconds after having been spray or immersion rinsed in clean water.

Sealed Anodized Coating: A CAA coating which is subsequently processed in hot, deionized water.

3.0 PROCESS CONTROL

WARNING Some of the materials employed herein are flammable and toxic. Consult appropriate facilities, equipment, ventilation and other requirements for safe operation and disposition.

Handle foil with clean gloves, to protect from fingerprinting, until foil has completed the required processing.

Figure A-1 shows the flow diagram for CAA of aluminum foil. Foils shall be processed from one step to the next without delay and without allowing the foil to dry. The one exception is that foils should be thoroughly dried following vapor degreasing before immersion into the alkaline cleaner.

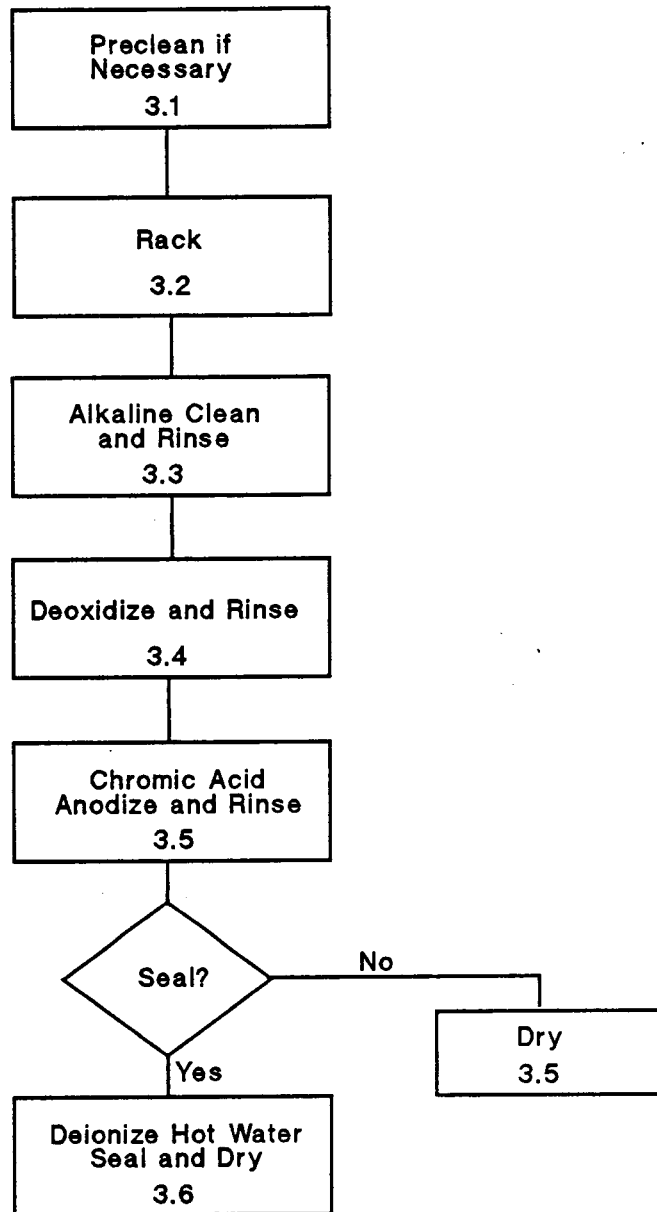


Figure A-1 Chromic Acid Anodizing Process Flow Diagram

3.1 Precleaning Prior To Racking

If visibly soiled, vapor degrease or manual solvent clean before racking foil. Manual solvent clean to remove tape residue, ink and or pencil marks. After vapor degreasing or solvent cleaning and prior to alkaline cleaning, foils should be thoroughly dried to prevent contamination of alkaline cleaner solutions with solvent. Do not use plastic clamps during the vapor degreasing process.

3.2 Racking

Foils shall be racked to provide a secure electrical contact with a minimum of contact area as this area will not anodize. Racking also provides the structural support required to keep the foil from wrinkling and creasing during the processes described in this specification. Use racks made from aluminum alloys (2024 is recommended), or titanium alloys. Aluminum racking should be stripped after each use.

Position foils to facilitate drainage and gas evolution. Do not rack different alloys on the same rack. Figure 4 (page 16) shows a racking scheme that was used successfully on 3-ft-wide by 25-ft-long aluminum foils. Note: The clamps are located such that they will not drain onto the anodizing surface. Do not use steel clamps during the anodize processing.

3.3 Alkaline Cleaning

As noted in 3.1, foils shall be free of excessive grease and oil before alkaline cleaning to minimize contamination in cleaning tanks and to ensure maximum alkaline cleaning effectiveness.

Potential alkaline cleaners are shown on page A-8. Agitate the alkaline solution after prolonged standing or after addition of chemicals or water to ensure uniformity of concentration. Completely immerse the racked foil in alkaline solution. When possible, lightly agitate alkaline solution during foil immersion to facilitate cleaning. Soak clean for 10 minutes, or until the surface is water-break-free after rinsing.

Spray or immersion rinse following alkaline solution. A light spray rinse is preferred prior to the immersion rinse to remove excess cleaner. Do not let the cleaner dry prior to rinsing. When immersion rinsing, soak for at least 5 minutes using foil or water agitation to facilitate rinsing. Agitate by raising and lowering foil in rinse water. Use a hot water rinse ($145^{\circ}\text{F} \pm 35^{\circ}\text{F}$) followed by a cold water rinse (room temperature is satisfactory). Foils are to be visually examined without magnification, after cleaning and rinsing. The foils shall be free of residue, smut, and soil and possess a water-break-free surface. Repeat step if required.

3.4 Deoxidize

After final rinse, completely immerse foil in deoxidizing solution. Potential deoxidizers are shown starting on page A-9. Immersion times vary with deoxidizer but are on the average 3-5 minutes with a cumulative maximum of 20-60 minutes. Agitate the deoxidize solution after prolonged standing or after addition of chemicals or water to ensure uniformity concentration. When possible, agitate deoxidizing solution during foil immersion.

Parts are to be sprayed or immersion rinsed following deoxidizing. A spray rinse is preferred prior to the immersion rinse to remove excess deoxidizer. When immersion rinsing, soak for at least 5 minutes using foil or water agitation to facilitate rinsing. Rinse water temperature should be approximately room temperature. Inspect for water-breaks. Repeat step if required.

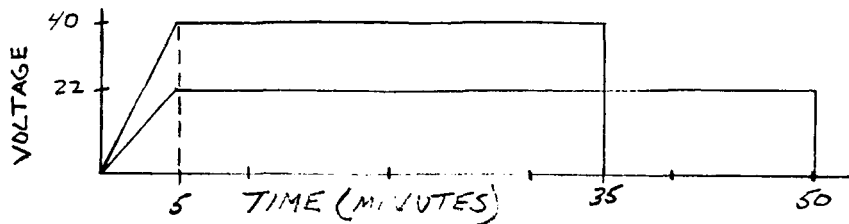
Periodically verify that deoxidizing solution constituents are in accordance with solution requirements. Use the analytical procedures and control points specified by the manufacturer.

3.5 Chromic Acid Anodizing

The following processing sequence shall be used to produce CAA films on 1145 aluminum alloy foil that meet the targeted optical values.

Completely immerse racked foils in anodizing bath with current on or apply current within 2 minutes after immersion of foil. Mildly agitate bath while anodizing. Use either of the following anodizing cycles to achieve the

targeted optical values. The 40 volt cycle is preferred. Prior to production runs, immersion times should be verified due to the possibility of processing variables.



Remove foils from the anodizing tank within two minutes after current is stopped. Rinse with cold water for approximately 15 minutes. During this time, raise and lower racked foil in rinse water to assure adequate rinsing of foil and racking.

When visually inspected, without magnification, the anodized foil shall be continuous, smooth, uniform in appearance and shall be free of powdery areas and discontinuities such as breaks and scratches.

If required, proceed to deionized water sealing immediately after rinsing. If no sealing is required, air dry at temperatures up to 160°F; drying time not to exceed 45 minutes.

3.6 Sealing Using Deionized Water

Operate seal water at 160°F to 210°F. Immerse foil for 5-8 minutes. Air dry up to 160°F maximum temperature. Drying time not to exceed 45 minutes. It is important to thoroughly dry the sealed foil.

4.0 MAINTENANCE

4.1 General Solution Preparation Procedure

Clean process tank thoroughly. Clean all electrical contact areas on the anodize tank, hood, and racks daily or as needed to maintain electrical continuity. Do not allow materials to cake on the bottom of the tank.

4.2 Alkaline Clean Solution

Fill tank to approximately half full of water. Distribute required quantity of cleaner uniformly over water surface, slowly and with thorough mixing. Heat solution to operating temperature. Add water to operating level and mix thoroughly. Bring solution to operating temperature.

4.3 Deoxidize Solution

Tanks of deoxidizer solution are prepared as follows unless otherwise noted on deoxidizer directions.

Fill tank to approximately half full of water. Add solid chemicals slowly by spreading uniformly over the surface. Agitate solution to dissolve chemicals. Add liquids acids slowly with agitation, allowing solution to cool to near operating temperature. Fill tank with water to operating level and agitate solution thoroughly. Bring solution to operating temperature.

4.4 Chromic Acid Anodize Solution

The following is a suggested method for making up the solution:

- 1) Fill the cleaned tank to half level with water.
- 2) Add 35 pounds of chromic acid per 100 gallons of final solution to the water, stirring ss necessary to dissolve. This solution will be 7% chromic, by weight.
- 3) Add water to bring solution to final volume and mix thoroughly.

4.5 Deionized Water Sealant

The contamination level of sealing water shall not exceed 12 ppm total solids of which not more than 3 ppm shall be silica. Determine purity of the seal water as often as required to maintain these limits. A pronounced drop-off in ability of the water to produce adequate sealing indicates an impurity build-up in the water. Operate the seal water at 160°F to 210°F.

4.6 Rinse Water

Total solids shall not exceed 200 ppm in the rinse tanks used for alkaline cleaning, deoxidizing and anodizing.

5.0 REQUIREMENTS

5.1 Measurements of Optical Properties

Solar absorptance measurements are to be performed in accordance with ASTM E-424, Method A, integrated over an AM-0 solar spectrum.

Total hemispherical emittance measurements are to be performed in accordance with ASTM E-408, method A. Samples are to be measured at room temperature.

Due to the possibility of processing variables influencing the final optical properties of the CAA foil, optical measurements should be taken at intervals determined by experience.

5.2 Storage of Anodized Aluminum Foil

After thorough drying, the sealed and/or unsealed anodized aluminum foil should be wrapped in clean oil-free paper or plastic film and stored in a controlled contamination area until future use.

ALKALINE CLEANERS

The alkaline cleaners recommended for the preceding CAA process are listed as "Immersion Cleaners - Medium Duty Soak". The Turco 2623 was used throughout the program including CAA of large area foils.

IMMERSION CLEANERS - MEDIUM DUTY SOAK

(Previously designated as catagories "C", "CL", "D" and "DL")

- a. Altrex; Diversey-Wyandotte Corp.
- b. Altrex 1079; Diversey-Wyandotte Corp.
- c. Cee Bee A54; McGren-Rohco, Inc.
- d. Detrex ALSW; Dexter Chemical Industries, Inc.
- e. Diversey 909; Diversey-Wyandotte Corp.
- f. Isoprep 44; Allied-Kelite Products
- g. Oakite 164; Oakite Products, Inc.
- h. Oakite 61B; Oakite Products, Inc.
- i. Pacific SP112/SP112-LF; Pacific Chemicals Mfg. Co.
- j. Pennwalt 2476; Pennwalt Corp.
- k. Pennwalt A-27; Pennwalt Corp.
- m. Ridolime 322; Amchem Products, Inc.
- n. Turco 2623 (Alumina Clean); Turco Products Div.
- p. Turco 3266 (Aviation); Turco Products Div.
- q. Turco 4090 (Airlion); Turco Products Div.

DEOXIDIZERS

The deoxidizers recommended for the preceding CAA process are given on the following pages. These underlined deoxidizers are classified as heavy duty with smut removal capabilities. Their individual solution make-ups follow. Amchem 6-16 or 6-17 was used for the majority of the program including CAA of large area foils. Deoxidizer labeled as solution 1, 9A, 22, 27 and 30 contain hexavalent chromium chemicals. Solution 37, called Boclene, is a Boeing patented (U. S. Patent No. 4,614,607) non-chromated deoxidizer/desmutter.

5.2 DETAIL SOLUTION REQUIREMENTS

5.2.1 SOLUTION 1 - ACP #2

	Initial Makeup per 100 Gallons			Control Limits		
	Sol. 1A	Sol. 1B	Sol. 1C	Sol. 1A	Sol. 1B	Sol. 1C
ACP #2	37 lb	37 lb	37 lb	5.4-6.4 oz/gal.	5.4-6.4 oz/gal.	5.4-6.4 oz/gal.
Nitric Acid	10 gal.	10 gal.	10 gal.	10-14 oz/gal. as HNO ₃	10-14 oz/gal. as HNO ₃	10-14 oz/gal. as HNO ₃
Hydrofluoric Acid	2.5 fl oz	---	1.3 gal.	As required for etch rate		
Etch Rate <u>1/</u>				0.0001-0.0002	0.00005-0.00009	0.0002-0.00035
Temperature				Room	Room	Room

1/ Etch Rate: Inch/surface/hour on 2024-T3 clad aluminum. Maintain this rate by additions of fluoride; adding 0.04 fl oz of hydrofluoric acid or 0.05 oz of ammonium bifluoride or Wyandotte MF per gallon of deoxidizer will raise the metal removal rate about 0.0001 inch/surface/hour.

5.2.9 SOLUTION 9 - NITRIC-HYDROFLUORIC ACID

	Initial Makeup per 100 Gallons		Control Limits	
	Solution 9A	Solution 9B	Solution 9A	Solution 9B
Nitric Acid	15 gallons	25 gallons	15-30 oz/gal. as HNO ₃	25-35 oz/gal. as HNO ₃
Hydrofluoric Acid (or Ammonium Bifluoride or Wyandotte MF)	13 fl oz	1.0 gallon	As required for etch rate	
Etch Rate <u>1/</u>			0.00015-0.0004	0.0015-0.003
Temperature			Room	Room

1/ Etch Rate: Inch/surface/hour on 2024-T3 clad aluminum. Maintain this rate by additions of fluoride; adding 0.04 fl oz of hydrofluoric acid or 0.05 oz of ammonium bifluoride or Wyandotte MF per gallon of deoxidizer will raise the metal removal rate about 0.0001 inch/surface hour.

	Initial Makeup per 100 Gallons		Control Limits	
	Solution 22A	Solution 22B	Solution 22A	Solution 22B <u>3/</u>
Smut Go No. 4	37 lb	37 lb	4-6 oz/gal. <u>1/</u>	4-6 oz/gal. <u>1/</u>
Nitric Acid	12 gal.	---	10.5-16 oz/gal. as HNO ₃	---
Sulfuric Acid	---	5 or 9 gal.	---	6.5-24 oz/gal. as H ₂ SO ₄
Etch Rate <u>2/</u>			0.00015- 0.0004	0.00015- 0.0004
Temperature				

1/ Add Smut Go No. 4 when necessary to maintain bath chemistry (Cr+6). Surplus chromic acid anodizing solution meeting BAC 5019 may be used as an option for up to half of each Smut Go No. 4 addition.

2/ Etch Rate: Inch/surface/hour on 2024-T3 clad aluminum. Maintain etch rate by additions of Smut Go #5 Additive or hydrofluoric acid.

3/ Do not use this makeup for cleaning for resistance welding.

	Initial Makeup per 100 Gallons			Control Limits		
	Sol. 27A	Sol. 27B	Sol. 27C	Sol. 27A	Sol. 27B	Sol. 27C
Deoxidizer <u>1/</u>				0.6-1.4 oz/ gal. as Cr+6	0.6-1.4 oz/ gal. as Cr+6	0.3-0.8 oz/ gal. as Cr+6
#4 or #7 Powder or #6 or #8 Liquid	19 lb or 7 gal.	19 lb or 7 gal.	11 lb or 4 gal.			
Nitric Acid	10 gal.	---	10 gal.	10-20 oz/gal. as HNO ₃	--- as HNO ₃	10-20 oz/gal.
Sulfuric Acid	---	5 gal.	---	---	10-14 oz/gal. as H ₂ SO ₄	---
Aluminum (max.)				2.3 oz/gal.	2.3 oz/gal.	2.0 oz/gal.
Etch Rate <u>2/</u>				0.00015- 0.0004	0.00015- 0.0004	0.00005- 0.0004
Temperature				Room	Room	Room

1/ Normally maintain using powder Replenisher #14 or #17, or liquid Replenisher #16 or #18. Use Deoxidizer #4, #6, #7, or #8 when necessary to increase the hexavalent chromium without greatly increasing the etch rate. Use #7, #8, #17, or #18 materials as necessary to prevent copper deposition on the parts. Any combination of the Deoxidizers or of the Replenishers may be used to meet the above requirements.

2/ Etch Rate: Inch/surface/hour on 2024-T3 clad aluminum. Maintain using Replenishers or Deoxidizers per 1/ or using fluorides. The following additions will increase the etch rate about 0.0001 inch/surface/hour: 1.0 oz/gal. of #14 or #17 Replenisher; 2.4 fl oz/gal. of #16 or #18 Replenisher; 4.25 oz/gal. of #4 or #7 Deoxidizer; 9.6 fl oz/gal. of #6 or #8 Deoxidizer; 0.20 fl oz/gal. hydrofluoric acid; or 0.23 oz/gal. ammonium bifluoride or Wyandotte MF.

	Initial Makeup per 100 Gallons	Control Limits
TEC 838-F	50 lb	8-16 oz/gal. <u>1/</u>
Nitric Acid	2.75 gallons	3.0 oz/gal. minimum as HNO ₃
Etch Rate <u>2/</u>		0.00015-0.0004
Temperature		Room

1/ In addition to controlling TEC 838-F by the Cr⁺⁶ equivalence, chromic acid may accompany the addition when the bath's sodium nitrate concentration exceeds 10 oz/gal. Chromic acid addition shall not be more than 4 times the weight of the TEC 838-F addition.

2/ Etch Rate: Inch/surface/hour on 2024-T3 clad aluminum. Addition of 1.0 oz/gal. TEC 838-F, as required for its control limits, increases the metal removal rate about 0.00003 inch/surface/hour. To increase the rate further, add 0.23 fluid ounce hydrofluoric acid per gallon of deoxidizer to increase the metal removal rate by about 0.0001 inch/surface/hour.

5.2.37 Change to read:

	Initial Makeup per 100 Gallons	Control
Nitric Acid (40-42 ⁰ Baume', Technical Grade)	50 gallons	6.2 to 8.0 Normal <u>1/</u>
Sulfuric Acid (50-53 ⁰ Baume', Technical Grade)	50 gallons	8.4 to 11.1 Normal <u>1/</u>
Ammonium Bifluoride (98 percent minimum, Technical Grade) <u>2/</u>	25 pounds	As required <u>3/</u>
Ammonium Nitrate (Technical)	8.4 pounds	As required <u>5/</u>
Temperature		60 to 95F
Etch Rate		0.8 mil/surface/hour maximum on 6061-T4 alloy <u>4/</u>

1/ Increase acid normalities by adding concentrated nitric acid (40 to 42 Baume') or sulfuric acid (66 Baume') as required.

2/ Actane 70 powder (Enthone Inc.) may be used in place of ammonium bifluoride until existing supplies are exhausted.

3/ Add ammonium bifluoride as required to obtain a smut-free appearance of deoxidized surfaces within the allowed immersion times. An add of 2 ounces of ammonium bifluoride per gallon of solution will increase the etch rate by approximately 10% and will restore an ineffective solution.

4/ Reduce etch rate by removing a volume of solution and replacing it with an equal amount containing nitric (40 to 42⁰ Baume') and sulfuric (50 to 53⁰ Baume') acids in a 1:1 ratio. Increase etch rate by adding ammonium bifluoride.

5/ Add as required to maintain etch rate below maximum. Total additions of ammonium nitrate may not exceed 10 grams/liter of deoxidizer.

5.2.38

SOLUTION 38 DIVERSEY 61/62

	<u>INITIAL MAKEUP PER 100 GALLONS</u>	<u>CONTROL LIMITS</u>
Diversey 61	100 gal.	Add no water Maintain freeboard level by adding Diversey 61 <u>1/</u>
Diversey 62	31.25 lbs (5 oz/gal.)	As required for etch rate; approx. 2 to 8 oz/gal.
Etch Rate <u>2/</u>		0.2-0.7 mil/surface/hour on 2024-T3 clad aluminum
Temperature		60-90°F

1/ When adding Diversey 61, always add Diversey 62 to maintain etch rate.

2/ Maintain etch rate near mid range. Etch rate test specimens are to be used no more than twice. Increase etch rate by adding Diversey 62. Decrease etch rate by drawing off volume of solution and replacing it with an equal amount of Diversey 61.

5.2.39

SOLUTION 39 - ACTANE 70

	<u>INITIAL MAKEUP PER 100 GALLONS</u>	<u>CONTROL LIMITS</u>
Water	25 gal.	
Nitric Acid	50 gal.	
Sulfuric Acid	25 gal.	
Actane 70 powder (add slowly when below 100°F)	37.5 lbs	As required for etch rate
Etch Rate <u>1/</u>		0.2-0.7 mil/surface/hour on 2024-T3 clad aluminum
Temperature		60 to 90°F
Solution Level		Maintain by adding nitric and sulfuric acids in a 2:1 ratio

***** Add concentrated sulfuric acid slowly to water while
C A U T I O N agitating to avoid splattering. Do not use solution
***** until it cools to control range.

1/ Maintain etch rate near mid range. Etch rate test specimens are to be used no more than twice. Increase etch rate by adding actane 70 powder. Decrease etch rate by drawing of a volume of solution and replacing it with an equal amount containing 2 parts nitric acid and 1 part sulfuric acid by volume.

5.2.40

SOLUTION 40 - BUZZ DEOXIDIZER #70

	<u>INITIAL MAKEUP PER 100 GALLONS</u>	<u>CONTROL LIMITS</u>
Buzz Deoxidizer #70 <u>1/</u>	31 lbs	2-6 oz/gal.
Nitric Acid	18 gal.	13-26 oz/gal. as HNO ₃
Etch Rate <u>1/ 2/</u>		0.00015-0.0004
Temperature		Room

1/ Include buzz deoxidizer replenisher #170.

2/ Etch Rate: Inch/surface/hour on 2024-T3 clad aluminum.

5.2.41

SOLUTION 41 - CLEPO 180-S

<u>COMPONENT</u>	<u>INITIAL MAKEUP PER 100 GALLONS</u>	<u>CONTROL LIMITS</u>
Clepo 180-S	87 lbs	12-16 oz/gal.
Temperature		Room

APPENDIX B
ADHESIVE BONDING OF ANODIZED ALUMINUM FOIL TO GRAPHITE/EPOXY TUBES
SPECIFICATION

1.0 SCOPE

This specification establishes the requirements for bonding sealed and unsealed CAA aluminum foil to Gr/Ep tubes using epoxy film adhesive.

2.0 ADHESIVES

Co-cured: foil that is bonded to Gr/Ep tubes at the same time the tubes are cured. The curing is performed in an autoclave using an epoxy film adhesive that is compatible to the cure cycle required for the Gr/Ep (recommended cure cycle is shown in Figure 2). Recommended film adhesives are 0.003" or 0.005" thick American Cyanamid FM 300 or equivalent.

Secondarily Bonded: Foil that is bonded to Gr/Ep tubes after tubes have been initially cured and then debagged. This approach requires tube surface preparation before applying foil/adhesive. Recommended curing is a 250°F oven for one hour with the foil/adhesive/tube under vacuum. Recommended epoxy film adhesives are 0.003" or 0.0005" American Cyanamid FM 73 or equivalent.

Primer: Primer is used to promote adhesion between foil and epoxy film adhesive. Spray primer onto backside of CAA foil. Primer selection depends on the cure cycle. Recommended primer for co-cured foil is 3M EC-3917 or equivalent and recommended primer for secondarily bonded foil is 3M EC-3960 or equivalent.

3.0 PROCESS WARNING

WARNING Some of the materials employed herein are flammable and toxic. Consult appropriate facilities, equipment, ventilation and other requirements for safe operation and disposition.

3.1 LAYUP AREA

Waxes, mold release compounds, compounds containing uncured silicone, or any other materials detrimental to adhesion are not allowed in the layup area.

No eating or smoking in the layup area.

Layup areas shall be separated or isolated from operations or conditions that generate excessive particulate matter such as machining and sanding operations and open outside doors.

Clean gloves shall be used when handling uncured adhesives and primers. White cotton gloves are acceptable.

3.2 STORAGE AND HANDLING OF ADHESIVES AND PRIMERS

Store film adhesives and primer as specified by the vendor. Protect film adhesives during storage from loads other than their own weight.

Condition refrigerated material to room temperature prior to opening and/or use.

Immediately before use, thoroughly mix each container or primer for not less than 5 minutes on a vibrating paint mixer or equivalent.

3.3 APPLICATION OF PRIMER

Apply primer to foil within 72 hours of completing anodizing processing. Primer thickness shall be 0.00015" to 0.0004" (0.15 to 0.4 mils). Only qualified spray operators shall be allowed to spray primer onto anodized foil. The capabilities of the spray operator shall be determined by measuring cured film thickness on sample parts. This qualification shall be done as often as required. Apply a continuous wet coating. Foils with insufficient or excessive primer or with visible droplets are unacceptable. Cure the primer for 20 to 30 minutes at 250°F. Cured primed foils with scratches are not acceptable.

Storage of CAA foil with cured primer at room temperature is acceptable if wrapped with clean oil free paper or plastic film and placed in a controlled contamination area.

3.4 APPLICATION OF FILM ADHESIVES

Before opening the film adhesive wrapper, condition refrigerated adhesives to room temperature. Condensation on the adhesive is detrimental to peel strength.

Apply only one layer of continuous film adhesive to the primed CAA foil surface. Do not fold, stretch or thin the film adhesive. Leave the separator sheet on the side of the adhesive which will be exposed to the atmosphere, as a protective cover. Press the adhesive smoothly and firmly in place, using care not to entrap any air. Vacuum bagging film adhesive to primed foil is recommended to ensure an excellent bond without air entrapment. Remove the remaining separator sheet just prior to application of the foil to the part. Splicing of film adhesive is unacceptable.

Wrapping of the foil/adhesive to the exterior surface of the tube can be accomplished using the same techniques used to wrap Gr/Ep plies onto the mandrel. Cut foil to a width that is the circumference of the tube plus an additional 0.5" to permit an overlap of the foil to itself after wrapping. Vacuum bag per standard technique.

If secondarily bonding foil, the surface of the cured tube requires preparation prior to applying the foil/adhesive. Recommended preparation consists of manually abrading the exterior surface of the tube with a SCOTCHBRITE conformal abrasive pad using moderate pressure. Abrade tube until gloss is removed. After abrasion, wipe the tube surface with a lint free cloth lightly soaked in MEK and allow tube to air dry. When wrapping the tube with the foil/adhesive, use moderate pressures as the tube has no internal support if the mandrel has been removed. Vacuum bag per standard technique.

3.5 QUALITY ASSURANCE

Tubes with pin holes in the bonded foil are unacceptable. The pin holes can easily be distinguished after curing by circular areas of cured epoxy bleed out through these holes.



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16. Abstract <p>The success of the Space Station graphite/epoxy truss structure depends on its ability to endure long-term exposure to the LEO environment, primarily the effects of atomic oxygen and the temperature cycling resulting from the 94 minute orbit. This report describes the development and evaluation of chromic acid anodized (CAA) aluminum foil as protective coating for these composite tubes. Included are: development of solar absorptance and thermal emittance properties required of Al foil and development of CAA parameters to achieve these optical properties; developing techniques to CAA 25 ft lengths of Al foil; developing bonding processes for wrapping the Al foil to Gr/Ep tubes; and atomic oxygen testing of the CAA Al foil.</p> <p>Two specifications were developed and are included in the report; "Chromic Acid Anodizing of Aluminum Foil Process Specification" and Bonding of Anodized Aluminum Foil to Graphite/Epoxy Tubes." Results show that CAA Al foil provides an excellent protective and thermal control coating for the Space Station truss structure.</p>					
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